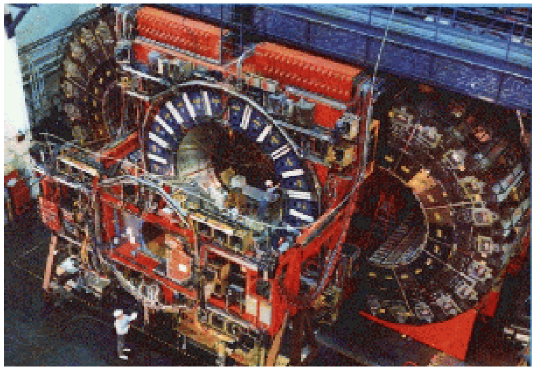
Searches For Higgs at CDF



Christopher Neu
Ohio State University

On behalf of
The CDF Collaboration

SUSY03
June 7, 2003

Outline:

- **Introduction and Motivation**
- **SM Higgs Production and Decay**
- **Run 1 Results**
- **MSSM Higgs Searches**
- **Summary**

Introduction and Motivation

Higgs searches are an important part of the Tevatron physics program.

Why?

•Source **of EWSB** in the SM:

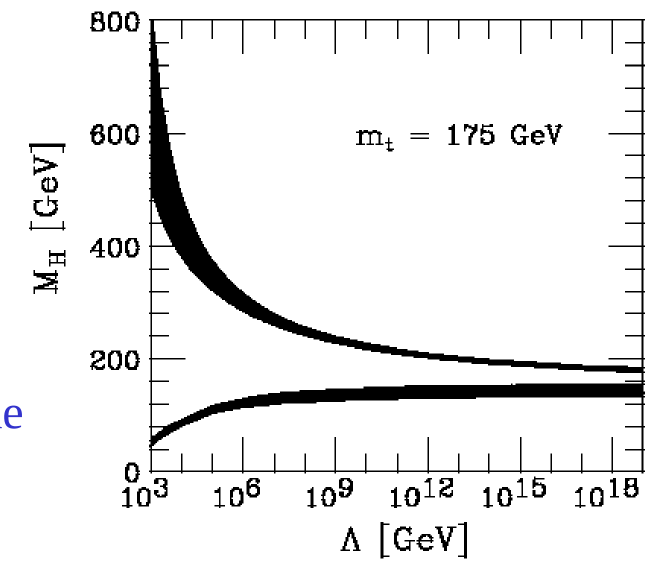
➢*Consequence:* ***imposition of mass*** *to elementary particles.*

•M_H: critical to the determination of L**:**

➢L **= energy scale at which the SM breaks down**:

➢*Could the SM be effective up to the Planck scale* (10^{19} *GeV*) *or does it break down at lower energies?*

•Tevatron: currently **only active facility** capable of probing the Higgs sector.

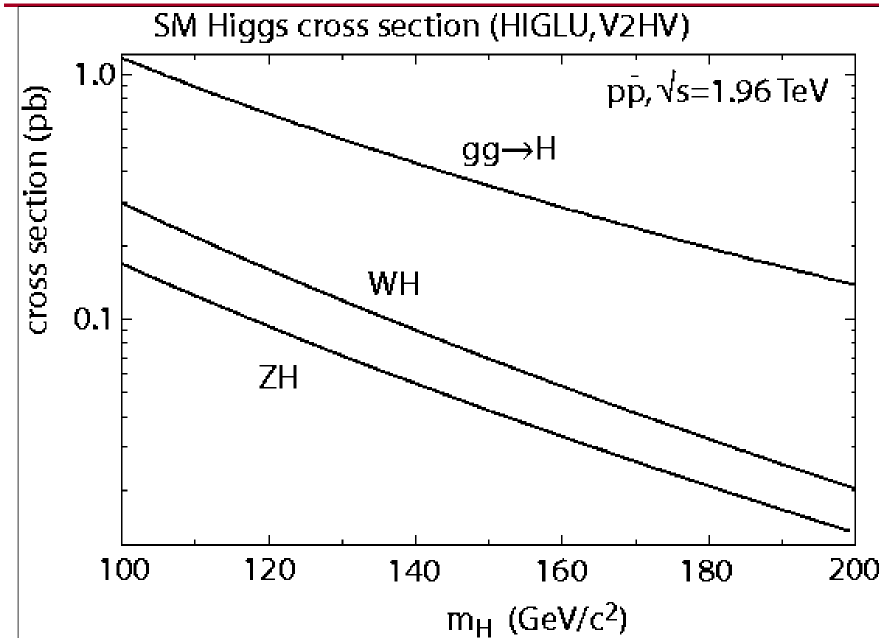


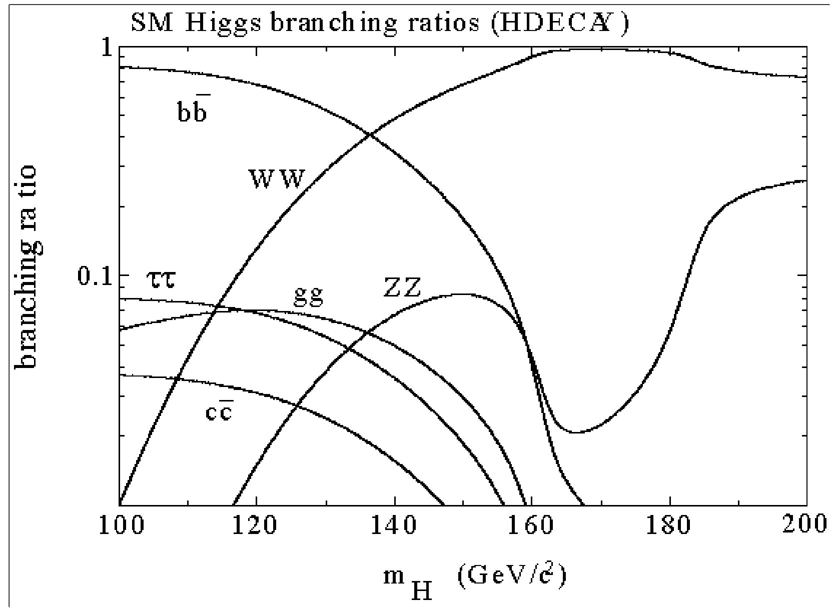
Present Limits on M_H:

$$M_H > 114.4 \frac{GeV}{c^2}$$ **Excluded by LEP at 95% CL**

$$M_H < 170 \frac{GeV}{c^2}$$ **From global SM fit at 95% CL**

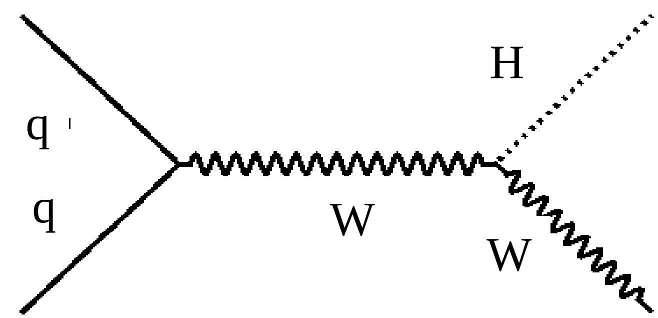
SM Higgs Production at the Tevatron





Higgs production and decay:

- Dominant production mode, ***gg*** → ***H*** :
  - enormous backgrounds
- Main targets: ***WH*** **and** ***ZH*** **production**
- **Main decay modes:**
  - ***H*** → ***bb*** for M_H<130
  - ***H*** → ***WW*** for M_H >130
- **Theory:** σ **(VH) = 0.05 — 0.2** ***pb*** (compare to $\sigma(tt)$~6 *pb*)
- Need luminosity…



Run I *VH* Limits

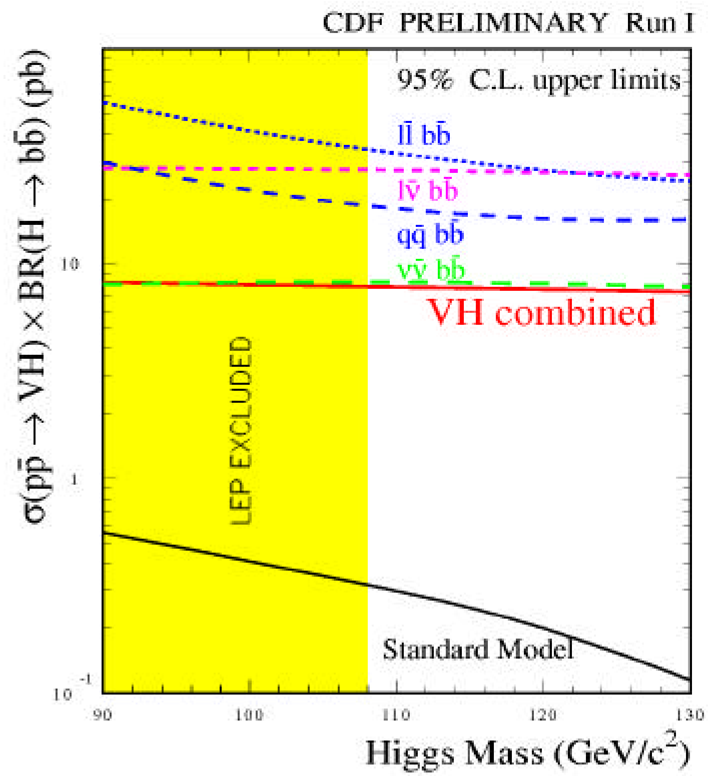
CDF performed several SM Higgs searches in Run 1:

- **Four channels:**
  - *WH ® lvbb*
  - *ZH ® llbb*
  - *ZH ® vvbb*
  - *W/ZH ® qqbb*

- *ZH ® vvbb* achieved best single-channel limit

- **Combined limit:**
  - Measured for *s*(VH)*BR(*H*→*bb*), *V*=*W* or *Z*
  - Binned likelihood, L, in M_{jj}
  - Minimized –ln(L) wrt *s*(VH)*BR
  - **Result: *s* (VH)*BR < 8*pb*** at 95% CL limit for M_H<130 *GeV*

- Limit is **~50 times larger** than theory prediction



Higgs Prospects for Run II

Tevatron Higgs Working Group

- Evaluated Run 2 Higgs search potential

- **Caveats:**
  - Approximate detector simulation
  - 10% dijet mass resolution
  - 60% per-jet tag efficiency
  - 100% trigger efficiency
  - Estimated background levels

MH=120, in lvbb final state, Lum = 1*fb*$^{-1}$:

Rate	CDF	SHW	Neural Net
S	3.7	4	4.4
B	49	58	26
S/sqrt(B)	**0.5**	**0.5**	**0.9**

hep-ph/0010338

- For WH, ZH modes, performed three studies:
  - **CDF Run 1 simulation**
  - **SHW simulation (~Run 2)**
  - **SHW simulation + Neural Network**

- ***Advocated employment of neural network***

WH Search Using a Neural Network

Primary question:

- Can we **demonstrate improved sensitivity** using a NN in the CDF Run 1 framework?

Further, we can also ask:

- Can we **optimize the strategy** using the Run 1 data with an eye to Run 2?
- Can this technique **reduce the Run 1 *WH* cross section upper limit**?

Prior-to-NN:

Backgrounds:

Source	Nexp
ttbar	5.4
Single top	2.5
Diboson	2.7
W+QCD	22.7
Total	**33.3**

Signal:

MH Scenario	Nexp
WH, MH=100	0.32
WH, MH=110	0.24
WH, MH=120	0.19
WH, MH=130	0.12
WH, MH=140	0.07
WH, MH=150	0.03

For M_H=120 baseline sensitivity:

$$\frac{S}{\sqrt{B}} = \frac{1}{30}$$

Strategy:
- Apply a **baseline event selection**
- Advanced selection:
  - Design a **NN** with **high background rejection**
  - Exploit M_{jj} in counting experiment
- **Optimize** using *a priori* limit as figure of merit
- **Investigate sensitivity gain**

WH Search Using a Neural Network

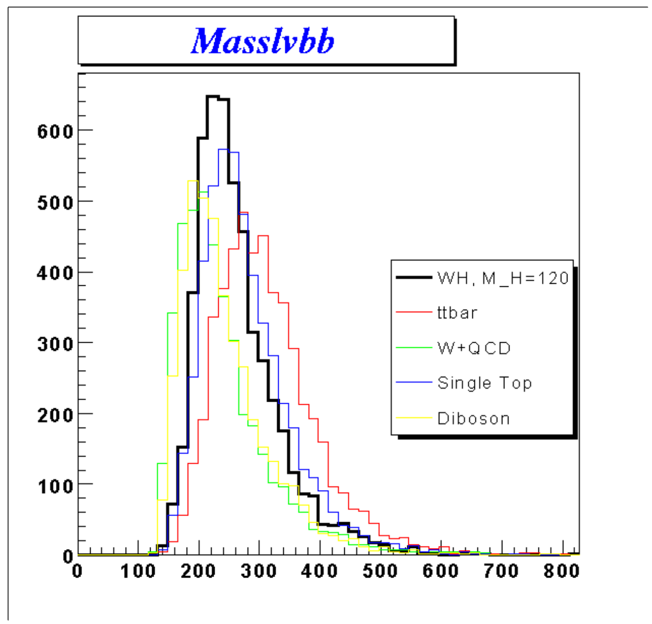
- **Baseline event selection:** high p_T lepton, MET, 2 jets, ≥1 b-tag
- **14 types of background**: sorted into **4 classes** ⇒ 4+1(signal) = **5 input classes**.

Class1	Class2	Class3	Class4	Class5
WH	*tt*	*Wbb*, *Wcc*, *Wc*, *W*+mistags, Non-*W*	*W**, *W*-gluon	*WZ*,*WW*,*ZZ*, *Zbb*,*Zcc*,$Z\rightarrow\tau\tau$

- Five input classes ⇒ 5 NN output nodes
- **Eight inputs**:

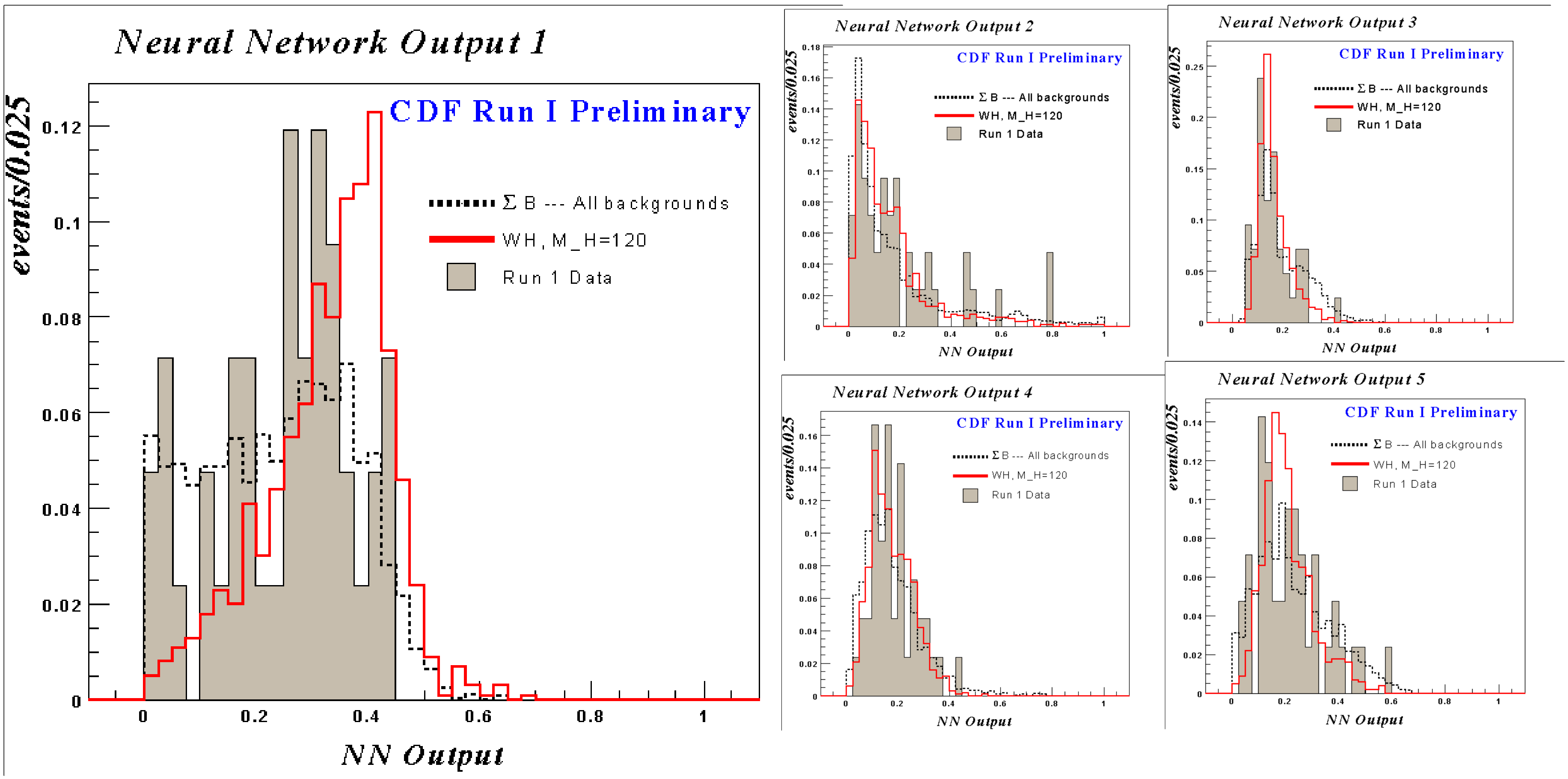
  - **MET**
  - H_T
  - **Vector** $p_T(j_1j_2)$
  - $(E_T^{j1} - E_T^{j2})$
  - $M_{j1j2Obj3}$
  - M_{lvj1}
  - SE_T^{Extra}
  - M_{lvj1j2}

➢ **Avoid using variables that sculpt** M_{j1j2}**!**



WH Search Using a Neural Network : Results From Data

- The CDF Run 1 W+2jet sample: 42 events
- Data events **run through our NN:**



WH Search Using a Neural Network: Data Results

Event yields after complete advanced selection:

CDF Run I Preliminary

	Signal		Data	
MH	(Theory)	Total	Observed	Probability
100	0.25+/-0.05	**12.6+/-2.6**	**19**	0.0899
110	0.20+/-0.04	**12.0+/-2.4**	**22**	0.0183
120	0.15+/-0.03	**10.6+/-2.1**	**21**	0.0092
130	0.09+/-0.02	**9.2+/-1.8**	**17**	0.0255
140	0.04+/-0.01	**7.2+/-1.4**	**15**	0.0141
150	0.02+/-0.005	**6.1+/-1.2**	**12**	0.0306

Estimated systematics

Conclusions:

- Post-advanced selection sensitivity: 1/22 for M_H=120 (34% improvemnt)
- We see a **2-3**s **excess** for each counting experiment
- This excess is known from other lepton+jets analyses

WH Search Using a Neural Network: Data Results

CDF Run I Preliminary

		Backgrounds						
	Signal		**Wbb,Wcc,Wc**		**Diboson,**		**Data**	
MH	**(Theory)**	**ttbar**	**W+mistags, nonW**	**Single Top**	**Z+X**	**Total**	**Observed**	**Probability**
100	0.25+/-0.05	1.4+/-0.4	8.8+/-2.5	0.9+/-0.2	1.5+/-0.4	**12.6+/-2.6**	**19**	0.0899
110	0.20+/-0.04	1.4+/-0.4	8.3+/-2.3	0.9+/-0.2	1.4+/-0.4	**12.0+/-2.4**	**22**	0.0183
120	0.15+/-0.03	1.3+/-0.4	7.2+/-2.0	0.9+/-0.2	1.2+/-0.3	**10.6+/-2.1**	**21**	0.0092
130	0.09+/-0.02	1.3+/-0.4	6.1+/-1.7	0.9+/-0.2	0.9+/0.2	**9.2+/-1.8**	**17**	0.0255
140	0.04+/-0.01	1.2+/-0.4	4.6+/-1.3	0.8+/-0.2	0.6+/-0.2	**7.2+/-1.4**	**15**	0.0141
150	0.02+/-0.005	1.0+/-0.3	3.9+/-1.1	0.7+/-0.2	0.4+/-0.1	**6.1+/-1.2**	**12**	0.0306

Estimated systematics

WH Search Using a Neural Network: Data Results

CDF Run I Preliminary

	A priori Limit		Data Results	
MH	**No Systematics**	**Estimated Systematics**	**Sigma(WH)**	**Sigma(VH)*BR(H->bb)**
100	9.5	11.3	17.8	22.5
110	8.4	9.9	19.9	24.1
120	8.4	10.0	21.8	23.4
130	9.3	10.9	21.4	18.0
140	13.5	15.6	33.3	18.5
150	24.3	28.5	55.2	17.9

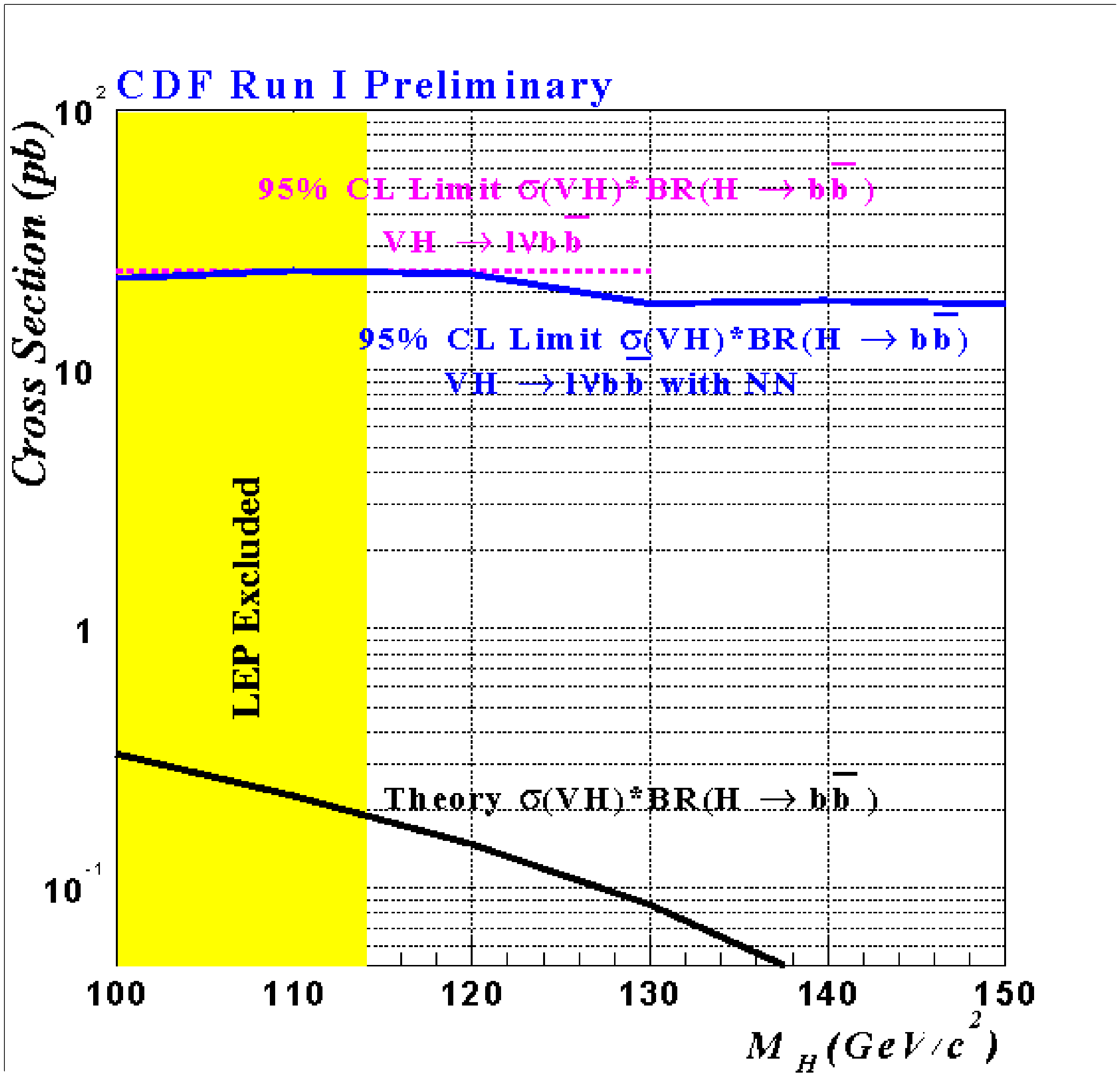
Note that the a priori limit from the previous Run 1 *lvbb* analysis was **~13*pb*** for M_H=120.

The improvement in a priori limit is the equivalent of having **an extra 60 pb^{-1} of Run 1 data**, an effective **increase of 57% from technique alone.**

Caveats:

- **This is not a fair comparison: No M_{jj} window exploited in previous Run 1 analysis.**
- **Estimated systematics for NN analysis.**
- A NN in other analyses (ex: double-tag analysis, N_{jets}=3 or 4, etc.) may have **different sensitivity increase.**
- **More fair comparison:** rectangular cuts analysis in same 8 variables with M_{jj} window

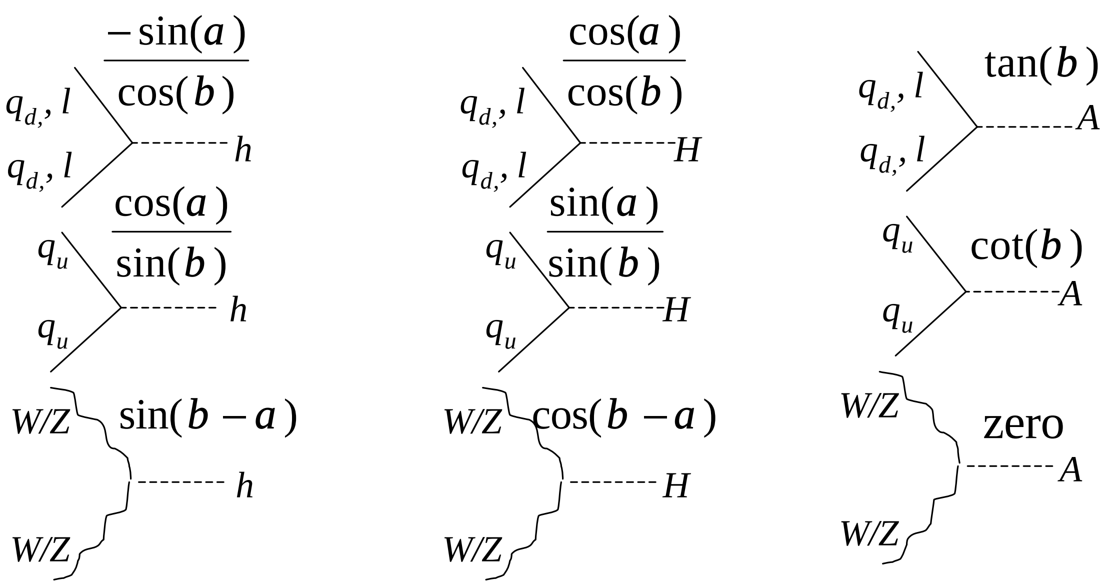
Results: Interpretation for *VH* Production Limit



MSSM Higgs in Run II

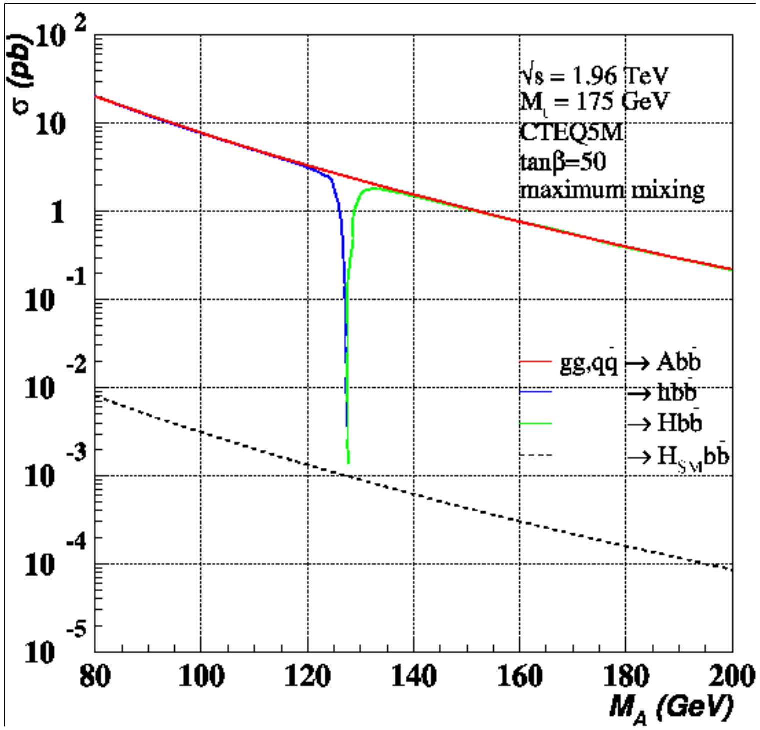
Minimal Supersymmetric Extension to the Standard Model (MSSM):

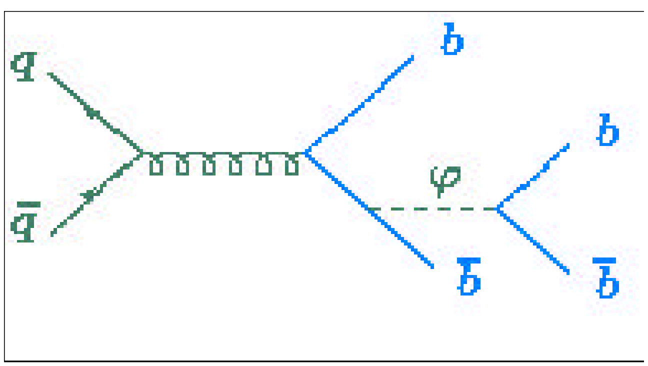
- Two Higgs doublets
- Five physical Higgs particles:
  - ➢Two neutral CP-even: *h*,*H*
  - ➢One neutral CP-odd: *A*
  - ➢Two charged: H^+ ,H^-
- Masses for all five described in terms of two free parameters: tan(β) and M_A
- Couplings are given by relations involving beta and alpha, the angle from the diagonalization of the h-H mass matrix



Enhancement for large tanβ values!

MSSM Higgs in Run II





•The $f f_d f_d$ coupling is **proportional to tan**b (f =h/H/A)

•If tanβ is large, the production cross section for the process **gg,qq** ® f **bb** is therefore **large as well.**

•Run 1 search looked for this channel

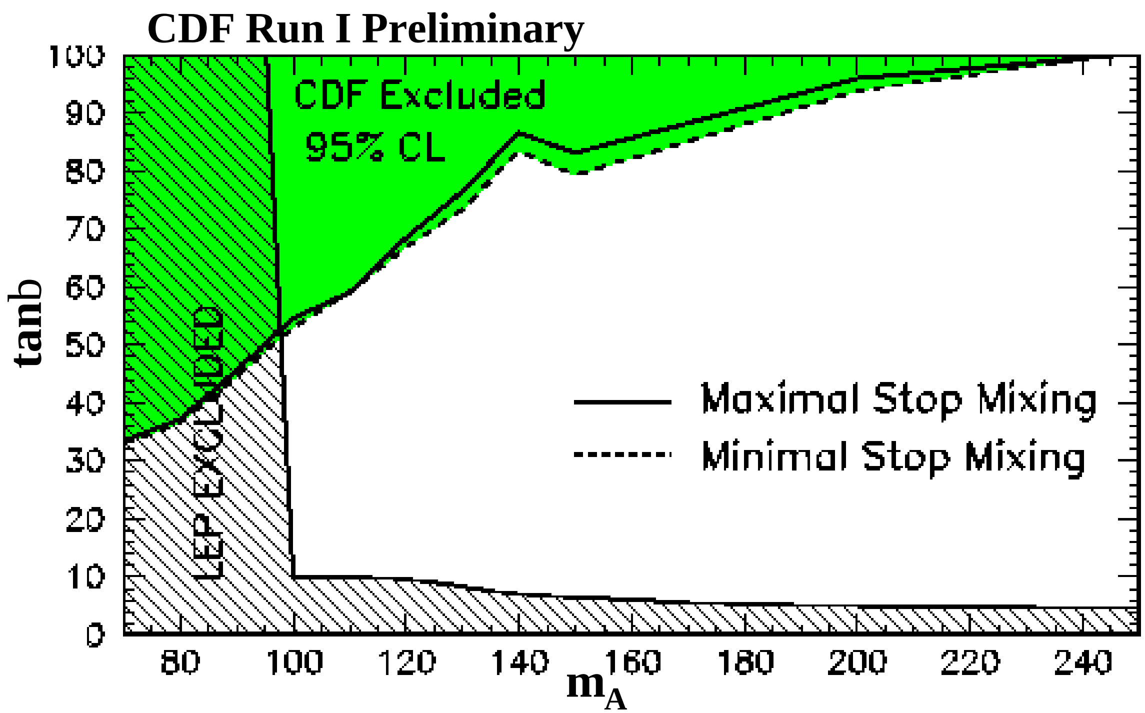
- Exploited decay A ® bb
- Looked for fairly clean bbbb final state.

•Event Selection:

- Four high ET jets
- 3 or more b tags
- Require tagged jets be well-separated
- M_f dependent cuts

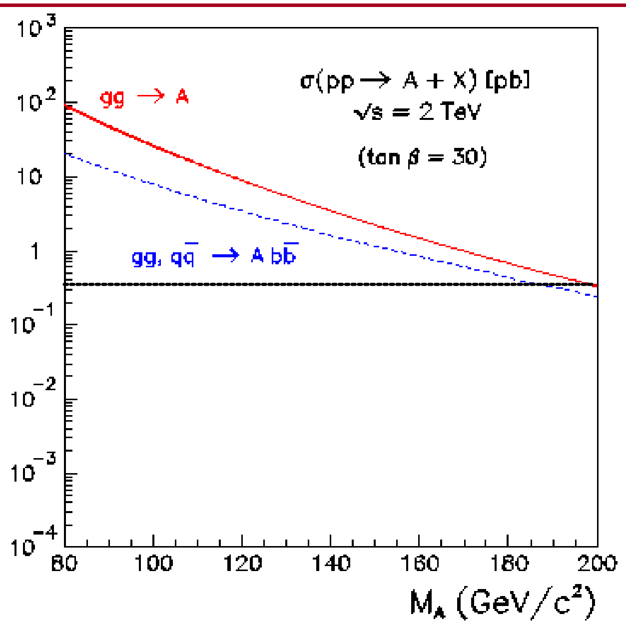
•Scanned M_f plane

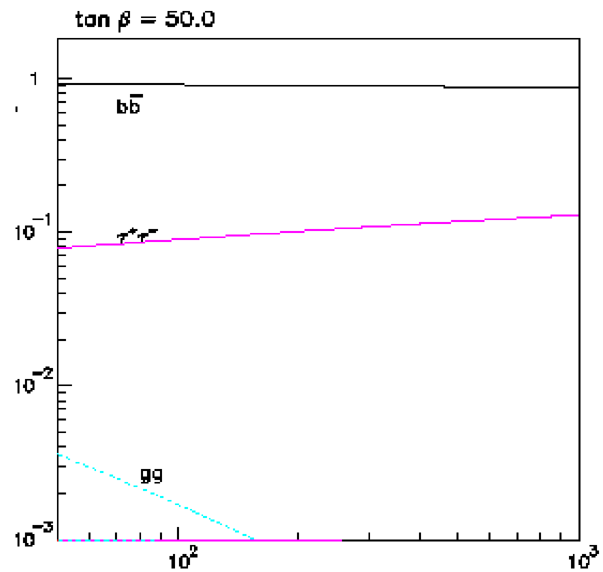
MSSM Higgs in Run II



- Large exclusion range outside of LEP results
- Exclusion of tanβ > 50 for M_A=100
- Opportunity to cover more of the phase space in Run 2
- Search is underway

MSSM Higgs in Run II





- tanβ enhancement also increases gg → A/H/h
- **Look for decay to taus instead of b's**
  - ➢Potentially much cleaner

t decay properties:

•t ® e?$_{e}$?$_{t}$, t ® μ?$_{μ}$?$_{t}$: leptonic decays (~ 36%).

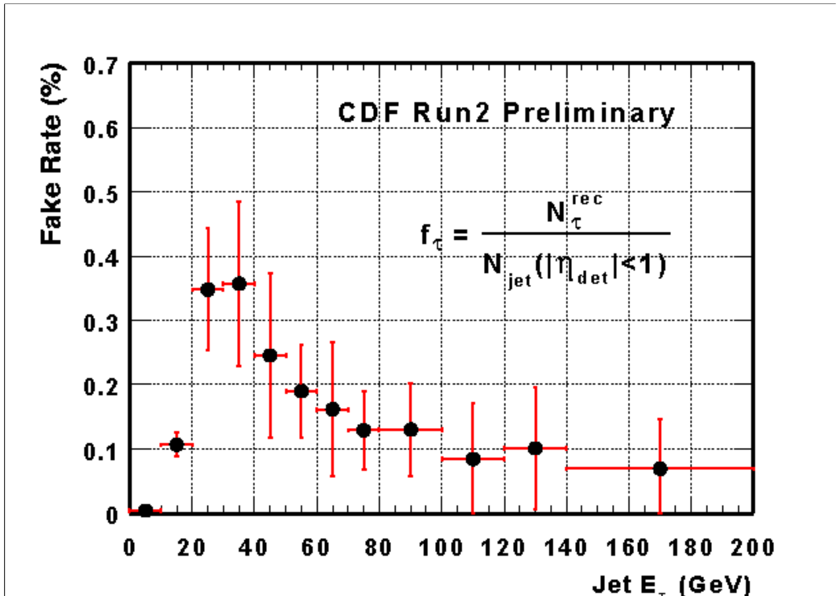
•t ® p?$_{t}$, t ® pp^{0}?$_{t}$, t ® ppp?$_{t}$: hadronic decays (~ 64%).

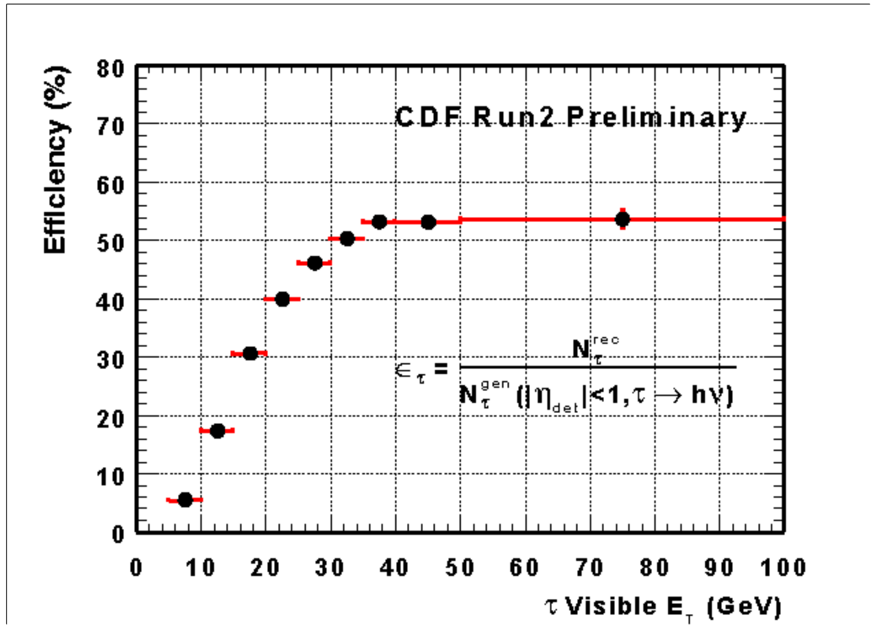
•Always accompanied by missing energy due to neutrinos in final state.

Identifying hadronic taus:

- Collimated, isolated jet
- Low track multiplicity
- Low π^0 multiplicity

MSSM Higgs in Run II





Run 1 analysis strategy:

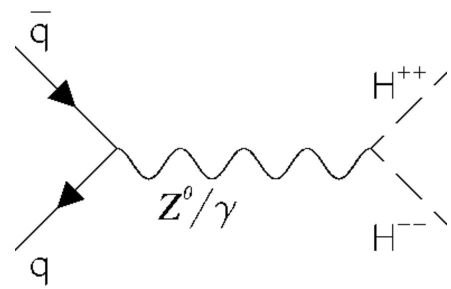
- High pT electron sample
- Look for
  - one tau decay to electron
  - one hadronic tau decay
- Require non-negative reconstructed tau mass for non-BTB candidates
- Perform counting experiment

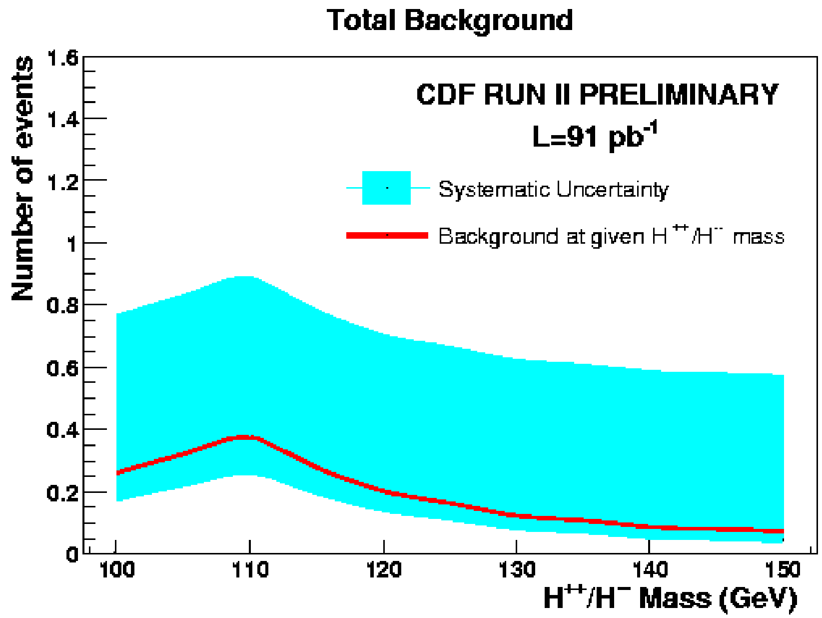
Run 1 analysis is nearing completion.
Run 2 analysis is off and running.

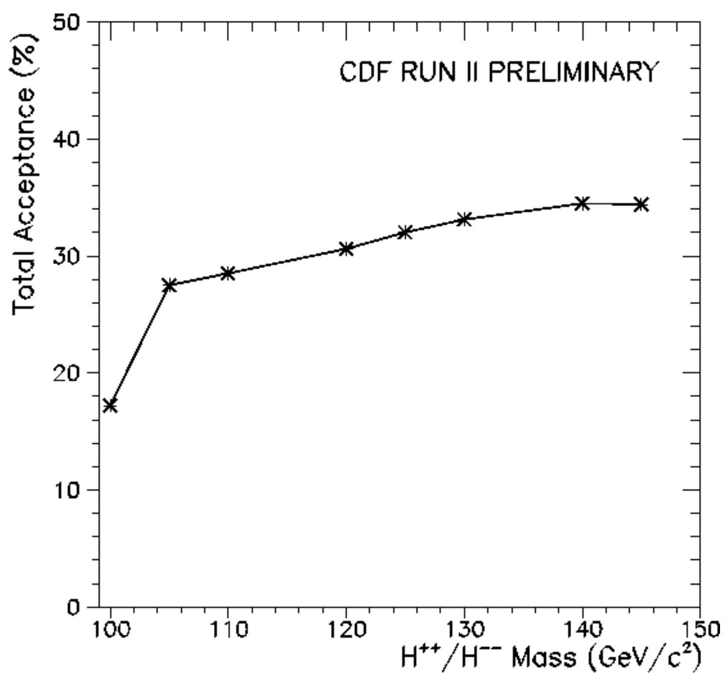
Exotic Higgs in Run II

Doubly-charged Higgs:

- •Predicted by L-R symmetric models
- •SUSY LR models predict low-mass H^{++}
- • $H^{++} \rightarrow l^+l^+$
- •Search performed in CDF Run2 same-sign **dielectron, dimuon data**

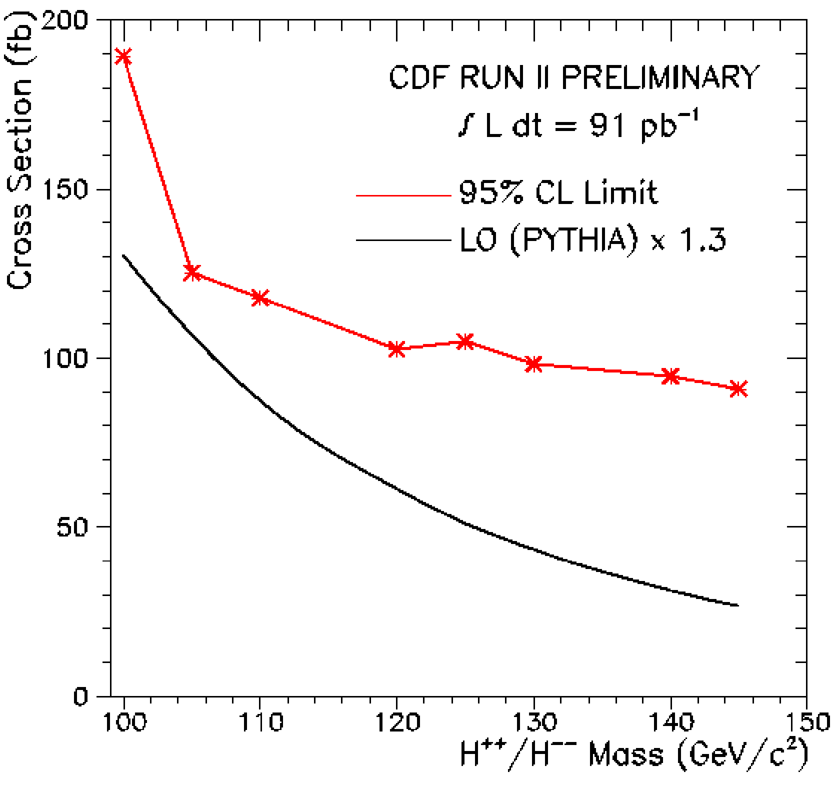


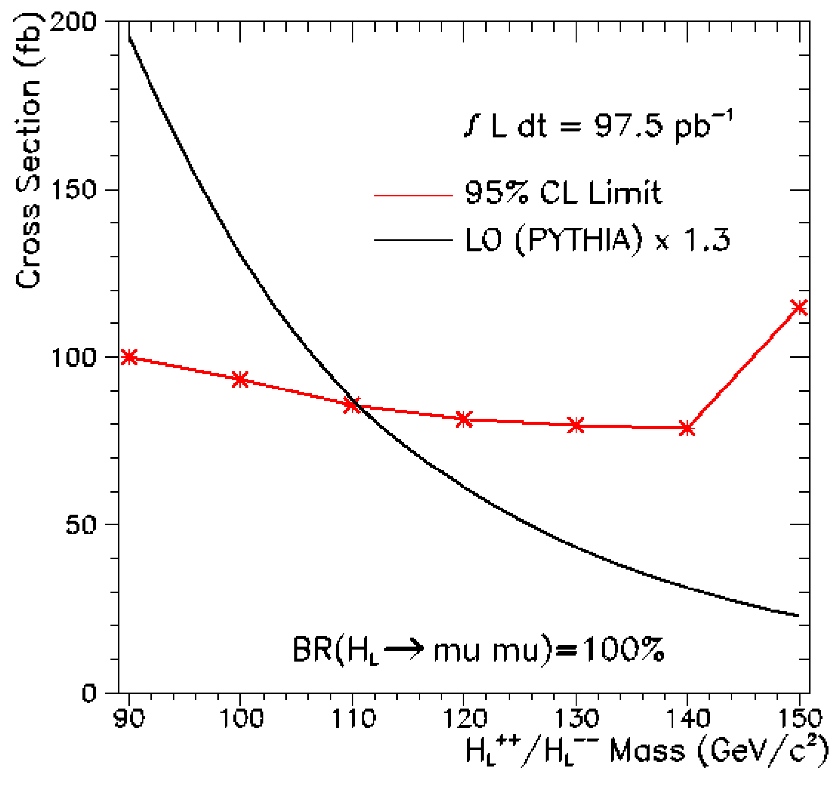




- •Backgrounds: Z production, QCD, W+jets cosmics(dimuon only)
- •Signal Acceptance: Pythia MC and CDF 2 detector simulation
- •Clean signal = high acceptance

Exotic Higgs in Run II





Dielectron Result:

- Observe 0 events
- Establish 95% CL limit
- No exclusion

Dimuon Result:

- Observe 2 events, expect ~3 from bkgd
- Establish 95% CL limit
- Restricts $M_{H++} > 110$ (LEP: $M_{H++} > 100$)

Summary

•The Higgs search is an important component of Run 2 CDF physics

•SM Higgs searches were performed in Run 1

•Gains from employment of a NN in advanced selection have been verified

•MSSM Higgs searches are underway that look for channels that enjoy tanβ enhancement

•Other exotic Higgs searches have been undertaken.

•There is much to be done!